Charm Production at RHIC

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Nu Xu -- LBNL

(1) Introduction

(2) Results from STAR (selected)

- electron spectra from p+p and d+Au
- Open charm hadron spectrum from d+Au
- v_2 from Au+Au

(3) Summary and outlook

Many Thanks to: **Organizers**
X. Dong, S. Esumi, H. Huang, H. Ritter, K. Schweda, P. Sorensen, **A. Tai**, Z. Xu
E.L. Bratkovskaya, L. Grandchamp, J. Raufeisen, R. Vogt

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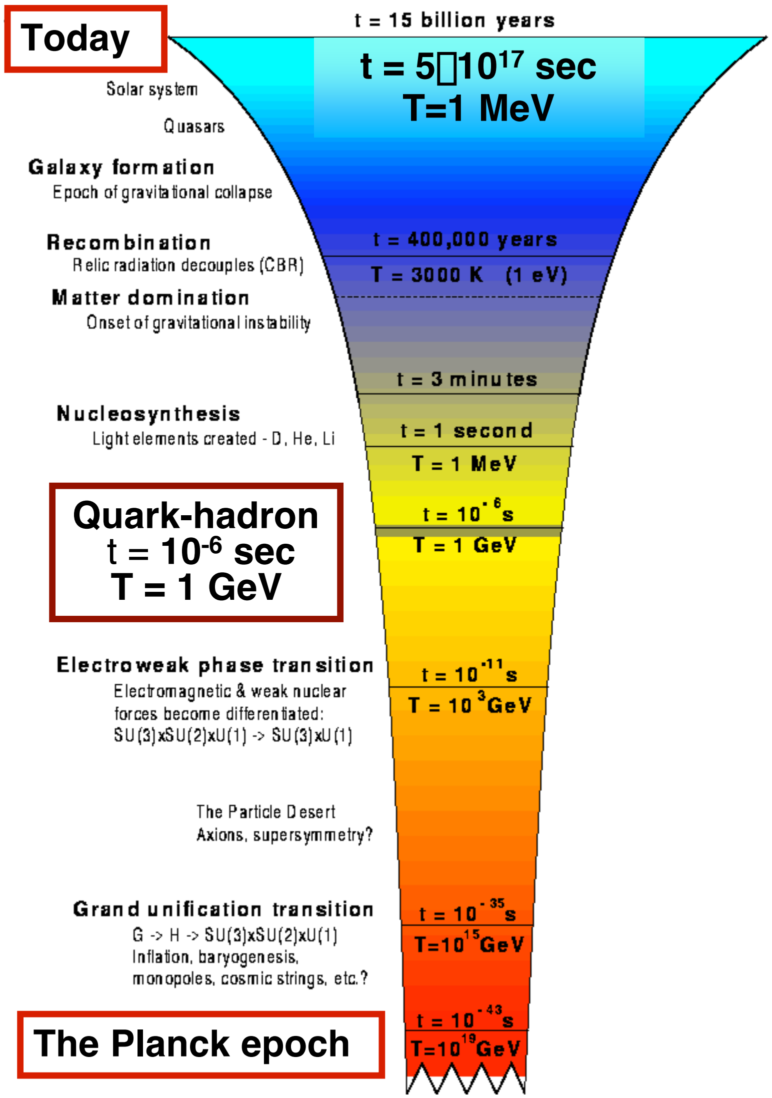
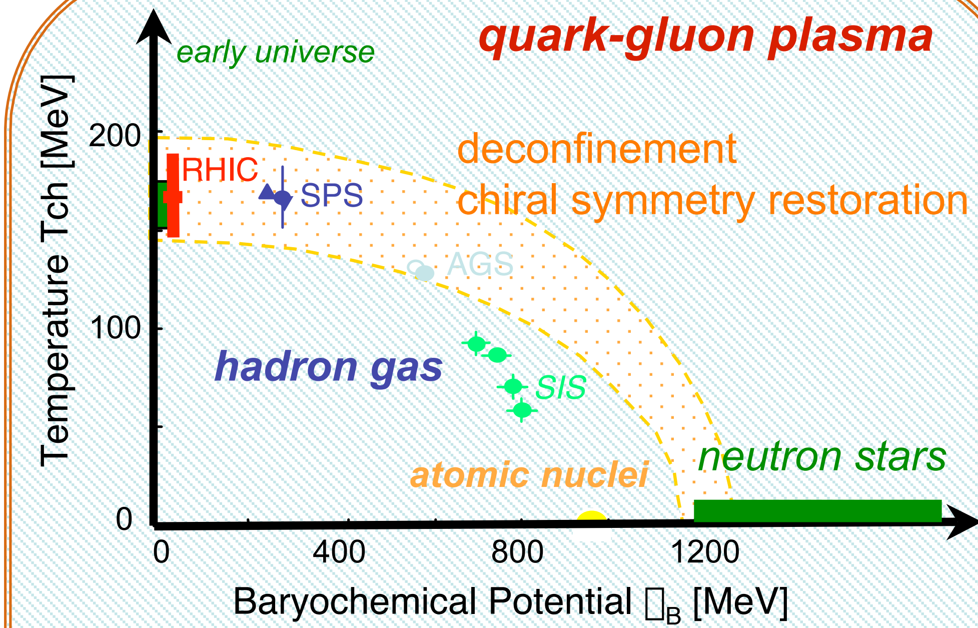
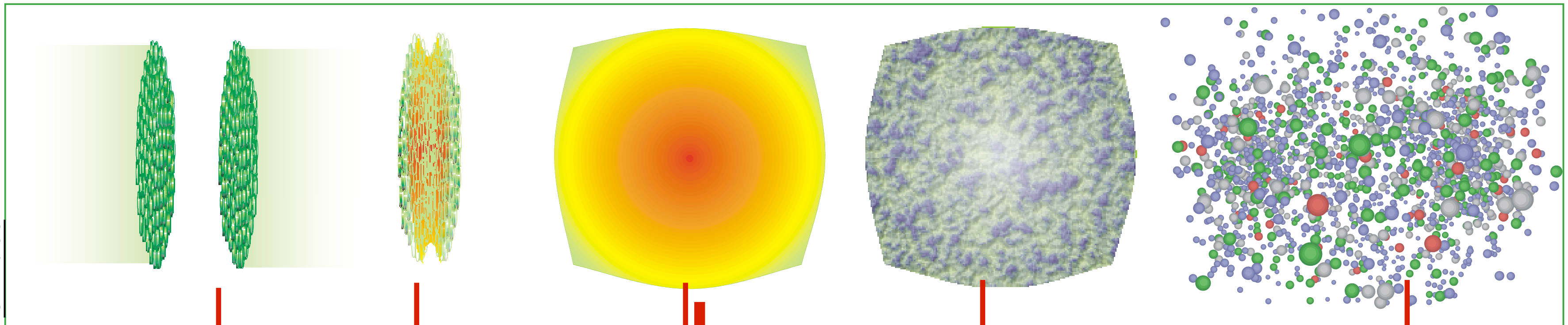
Predictions from QCD: The QGP





A QGP is believed to have existed in the first few moments after the big bang, and presumably at the center of neutron stars.

High-energy nuclear collisions



S. Bass

Initial conditions

Initial high Q^2 interactions

Parton matter - QGP
- The hot-QCD

Hadronization and Freeze-out

Experime... a...roac...

- Energy ...
- Elliptic f...
- Charm - productions plus the combination (1) and (2)

(1) Hard scattering production - QCD prediction
(2) Interactions with medium - deconfinement/thermalization
(3) Initial parton density

(1) Initial condition in high-energy nuclear collisions
(2) The cold-QCD-matter, small-x, high-parton density
- parton structures in nucleon / nucleus

QCD Energy Scale

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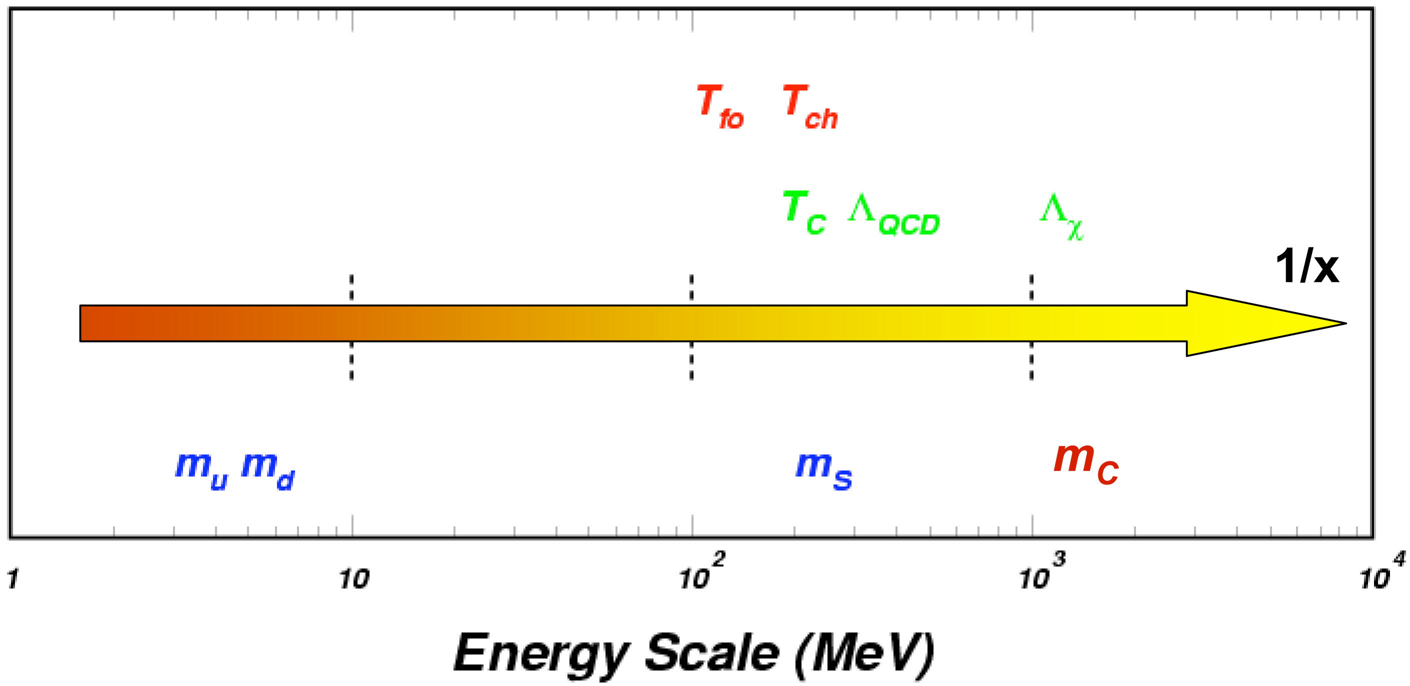


s-quark mass ~ 0.2 GeV, similar to values of

T_C critical temperature

Λ_{QCD} QCD scale parameter

T_{CH} chemical freeze-out temperature

$\Lambda_\chi = 4\pi f_\pi$ chiral breaking scale

c-quark mass ~ 1.2 - 1.5 GeV >> Λ_{QCD}

-- pQCD production - parton density at small-x

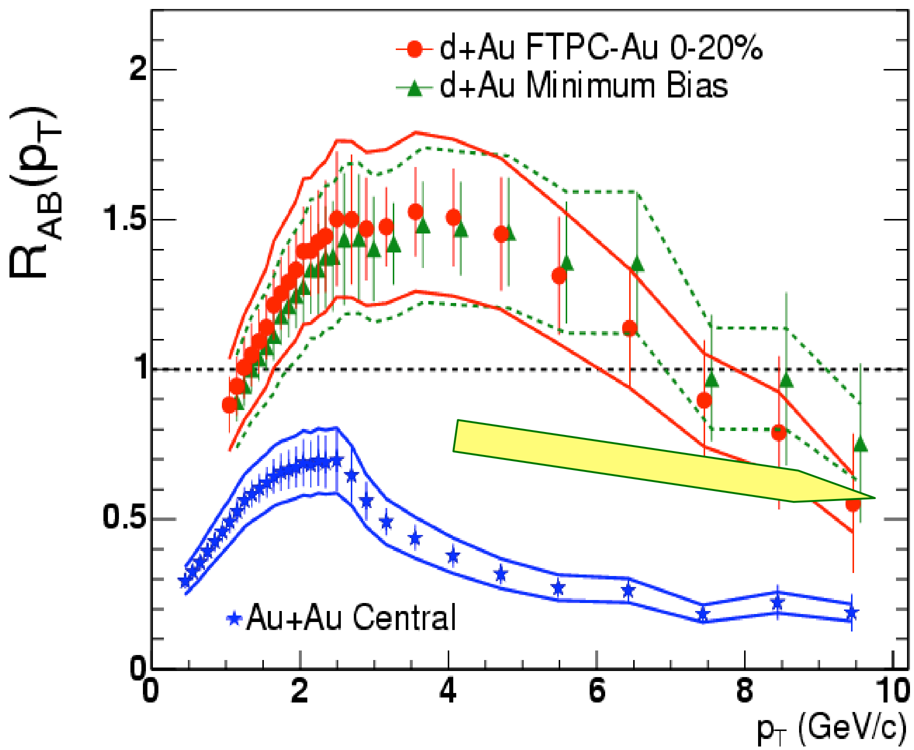
-- QCD interaction - medium properties

$R_{cc} \sim 1/m_C$ => color screening

J/ψ => deconfinement and thermalization

u-, d-, s-quarks: ***light-flavors*** || c-, b-quarks: ***heavy-flavors***

Energy Loss, Dead-cone Effect



Energy Loss:

1) Heavy quark gluon radiation is reduced in the colored medium
2) Less energy loss for charm-hadrons -> less suppressions
3) Test partonic energy loss assumption
4) Implication on both open- and close-charm hadrons spectra!

M. Djordjevic and M. Gyulassy, nucl-th/0404006
Yu. Dokshitzer and D. Kharzeev, Phys. Lett. ***B519****, 199(2001)*

J/ via coalescence

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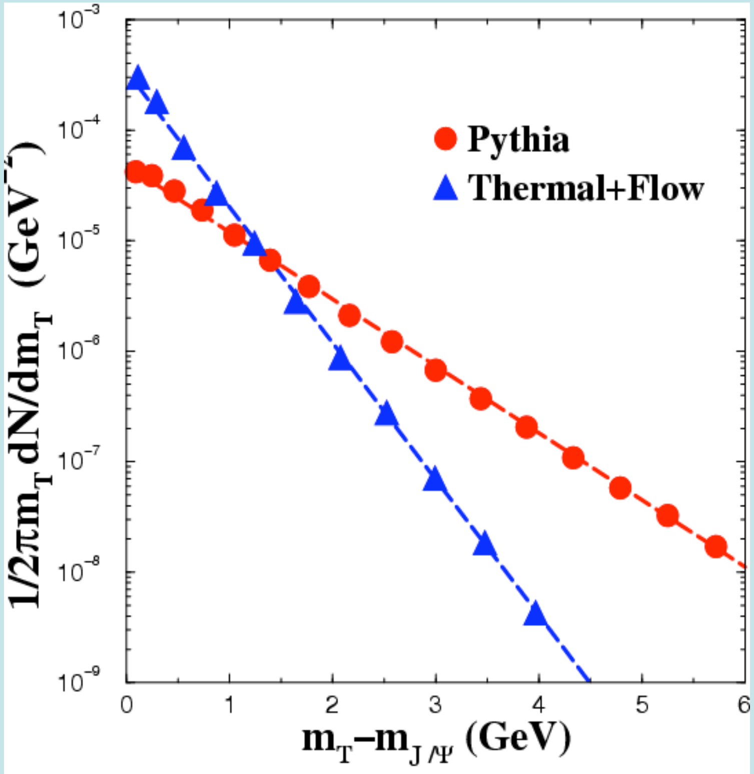

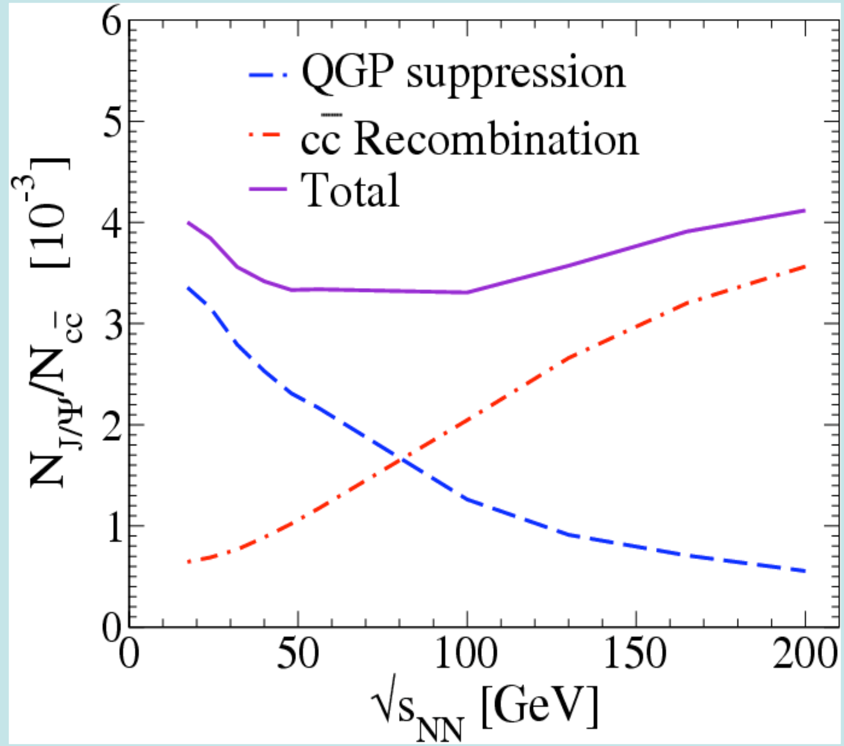

L. Grandchamp and R. Rapp, hep-ph/0209141(02)

J/: in central AA collisions, due to interaction with light flavors, values of mean p_T decrease and yields increase

➪ ***deconfinement and thermalization for light flavors***

Open-/closed-charm hadron yields

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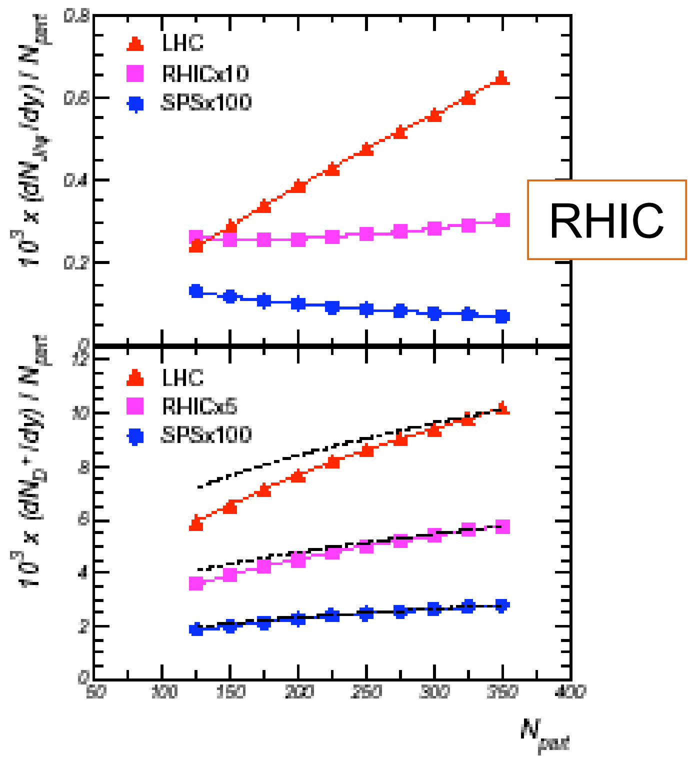
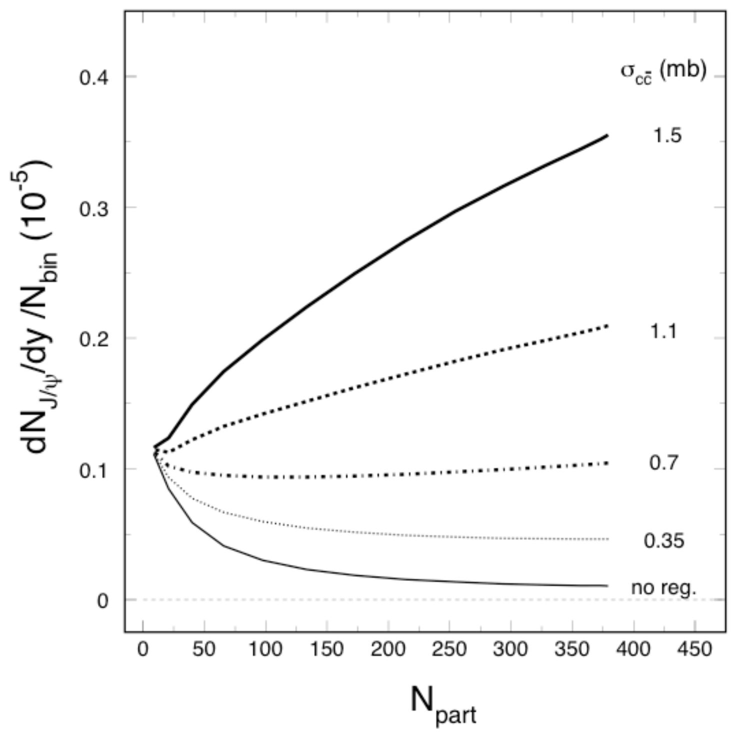
A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Phys.Lett. **B571** , 36(03).

L. Grandchamp and R. Rapp, Phys. Lett. **B523** , 60(01).

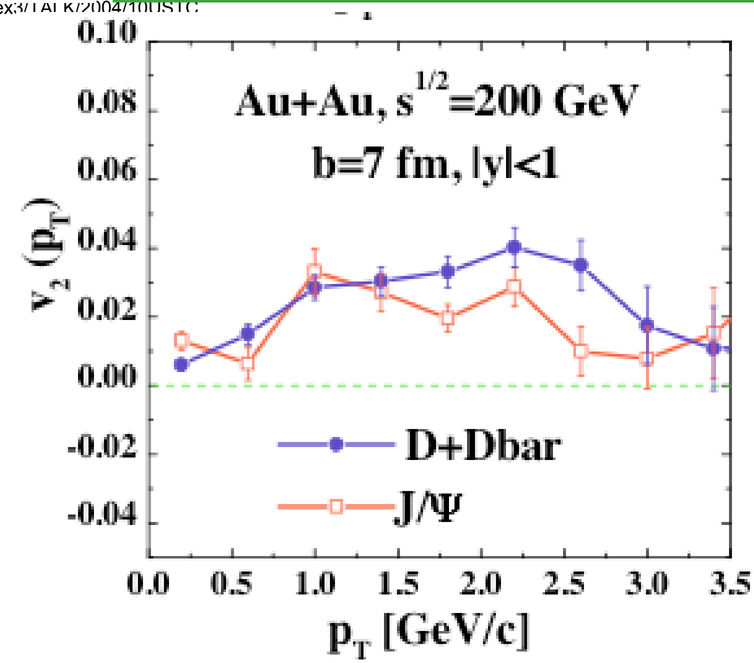


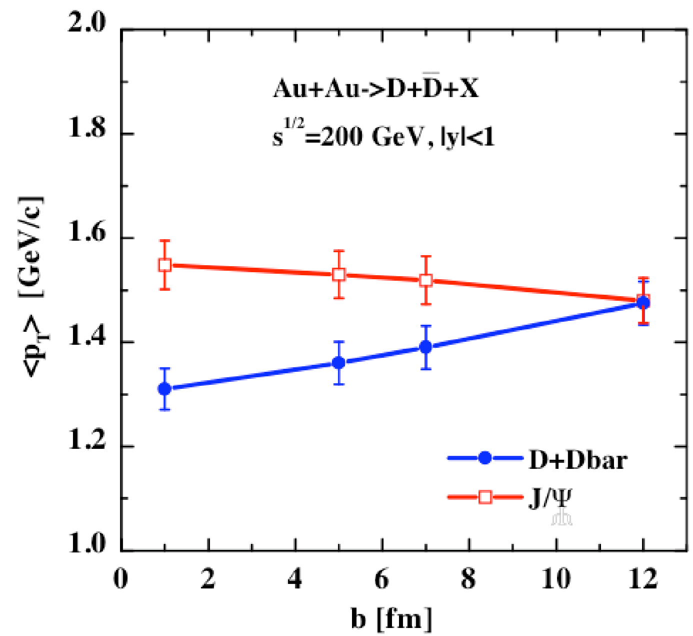


(1) open charm cross;
(2) direct pQCD production;
(3) medium effects (□ properties);
(4) absorption (color screening)

Model results are different, centrality dependence measurements are important!

Charm collectivity at RHIC





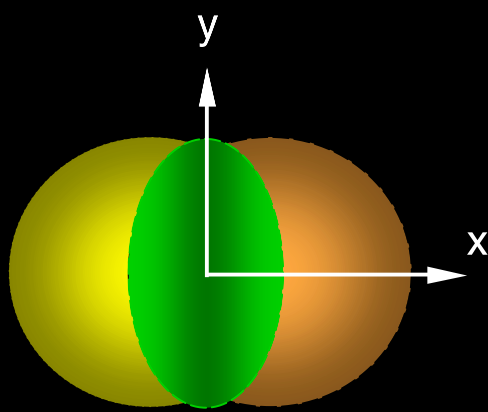
Through multiple rescatterings, partonic/hadronic, collective motion has been developed for charmed hadrons at RHIC!

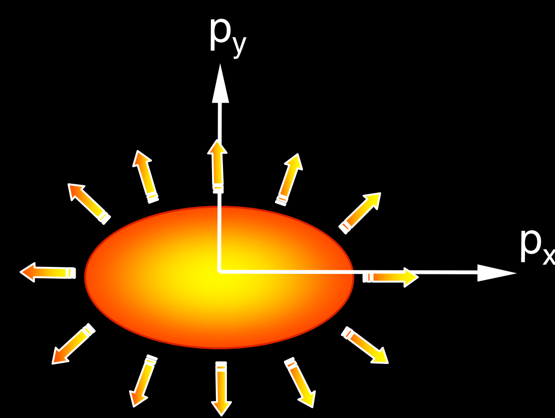
1) D-mesons lose their energy due to the hard spectrum at production
2) J/ increase in p_T due to coalescence process
3) Both attained finite value of elliptic flow v_2

HSD Model: *E.L. Bratkovskaya, W. Cassing, H. Stocker, and N. Xu,* ***nucl-th/0409047 (2004)***

Anisotropy parameter v_2

coordinate-space-anisotropy ⇒ momentum-space-anisotropy

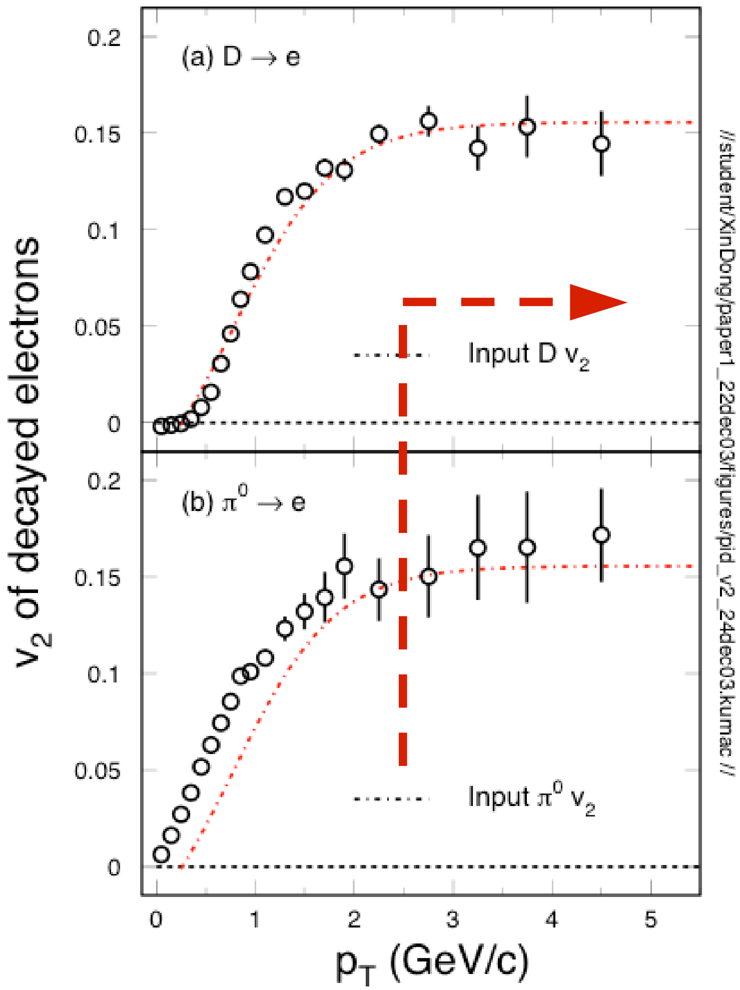




$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \;\; \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

Open charm v_2

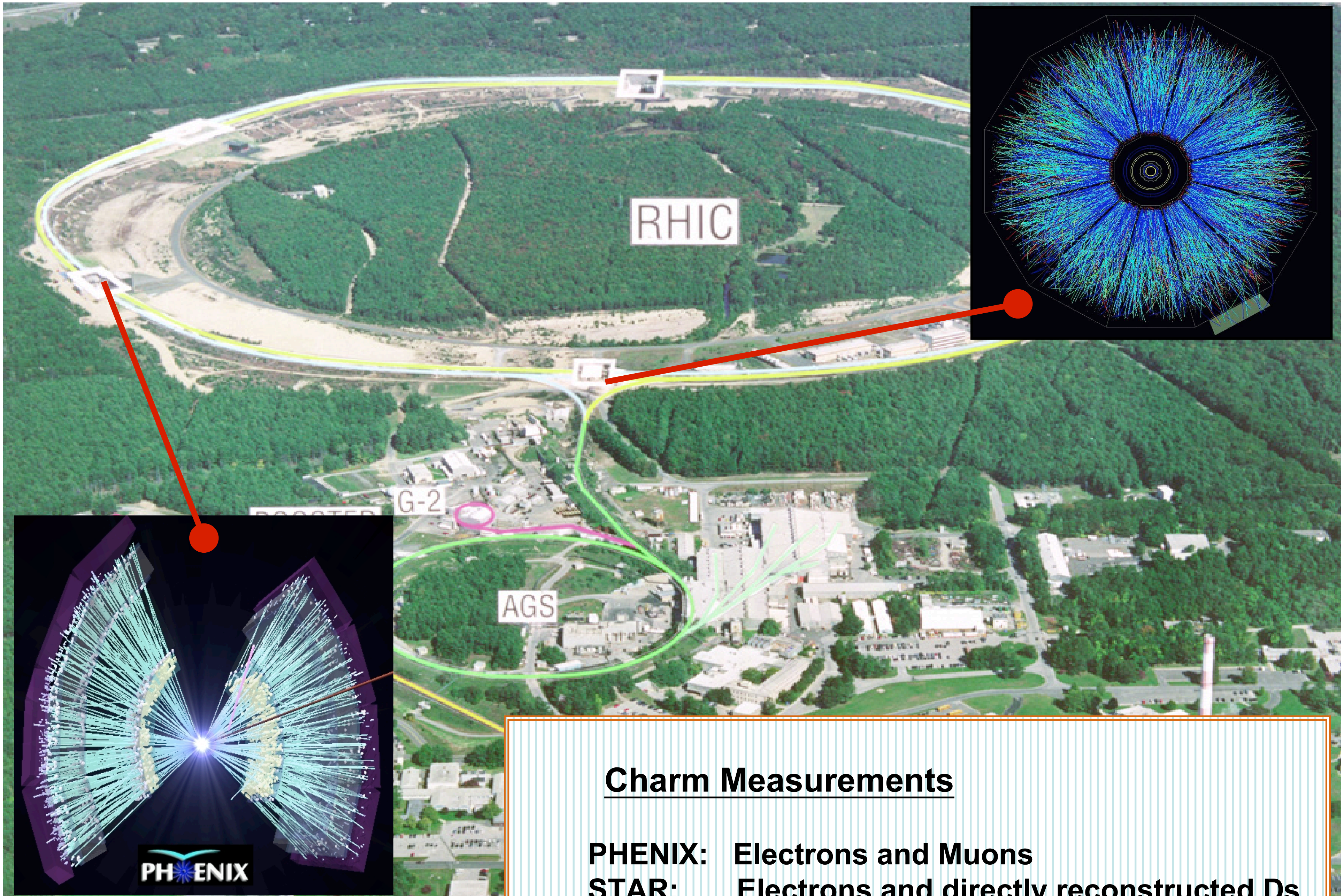


At p_T > 2.5 GeV/c:

1) D-meson spectrum is 'hard', yields of pion will be small, measure D-decayed electron to infer the open charm v_2

2) D-meson flow ➪ indication of light flavor thermal equilibrium.

X. Dong, S. Esumi, P. Sorensen, N. Xu and Z. Xu, Phys. Lett. **B597**, 328(2004).



Charm Measurements

PHENIX: Electrons and Muons
STAR: Electrons and directly reconstructed Ds

STAR: TPC & MRPC-TOF

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A new technology - Multi-gap Resistive Plate Chamber (MRPC), adopted from CERN-Alice

➢A prototype detector of time-of-flight (**TOFr**) was installed in Run3

➢One tray: ~ 0.3% of TPC coverage

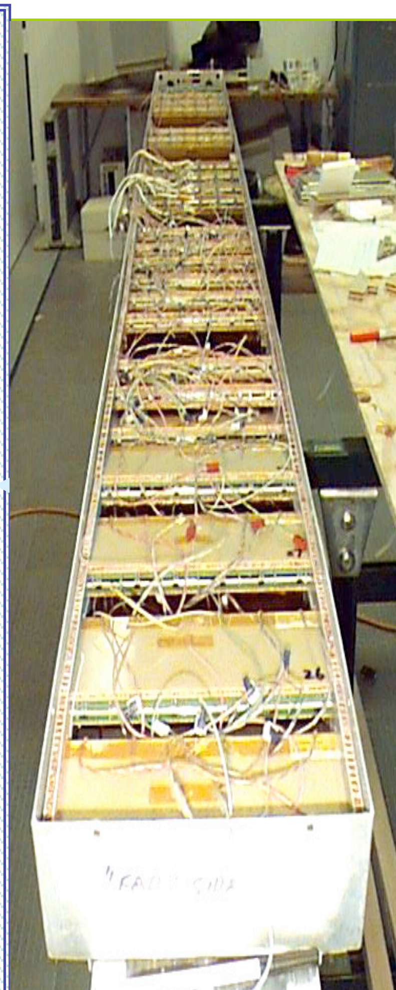
➢Intrinsic timing resolution: ~ 85 ps

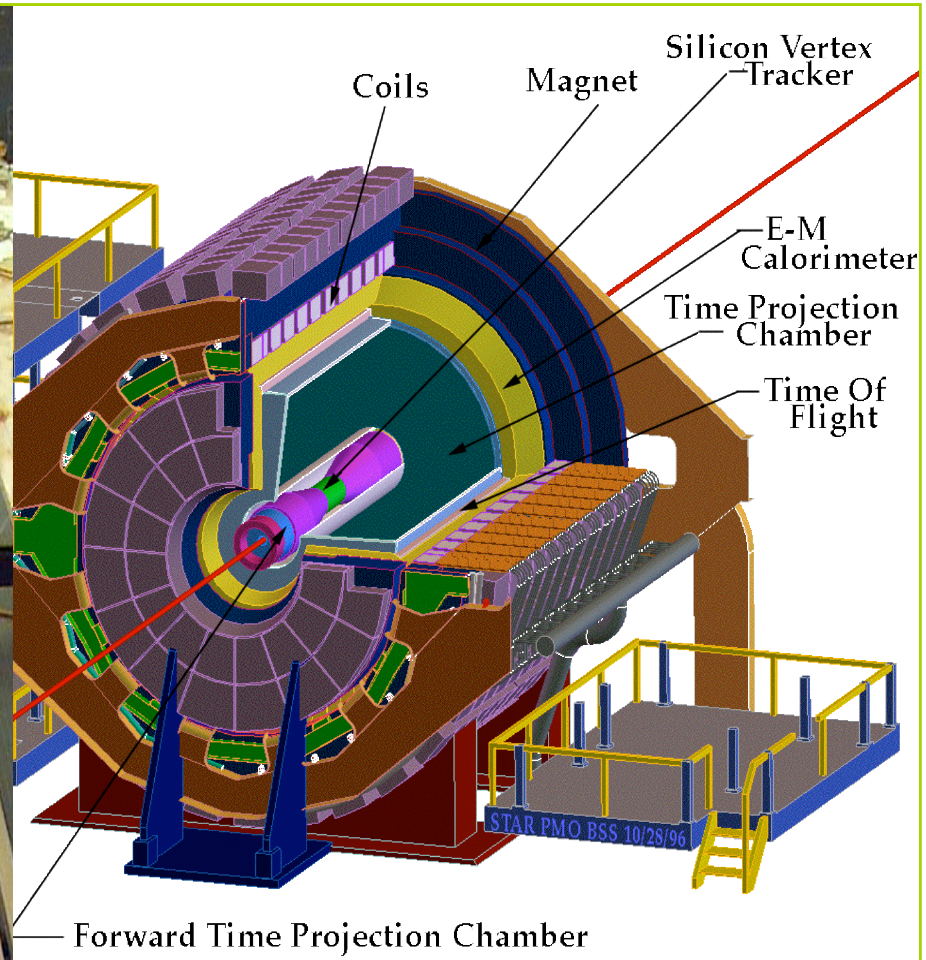
pion/kaon ID:

p_T ~ 1.7 GeV/c

proton ID:

p_T ~ 3 GeV/c





TPC dE/dx PID:
pion/kaon: p_T ~ 0.6 GeV/c; proton p_T ~ 1.2 GeV/c

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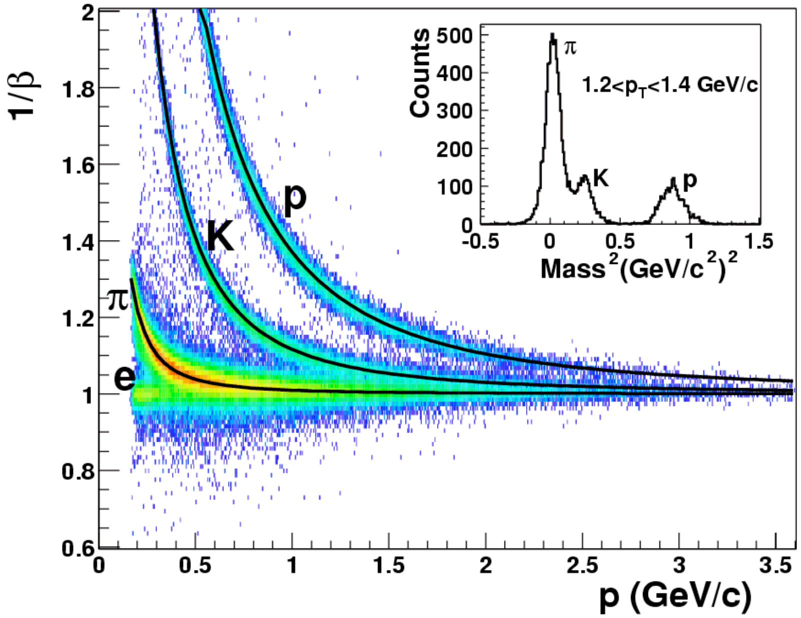
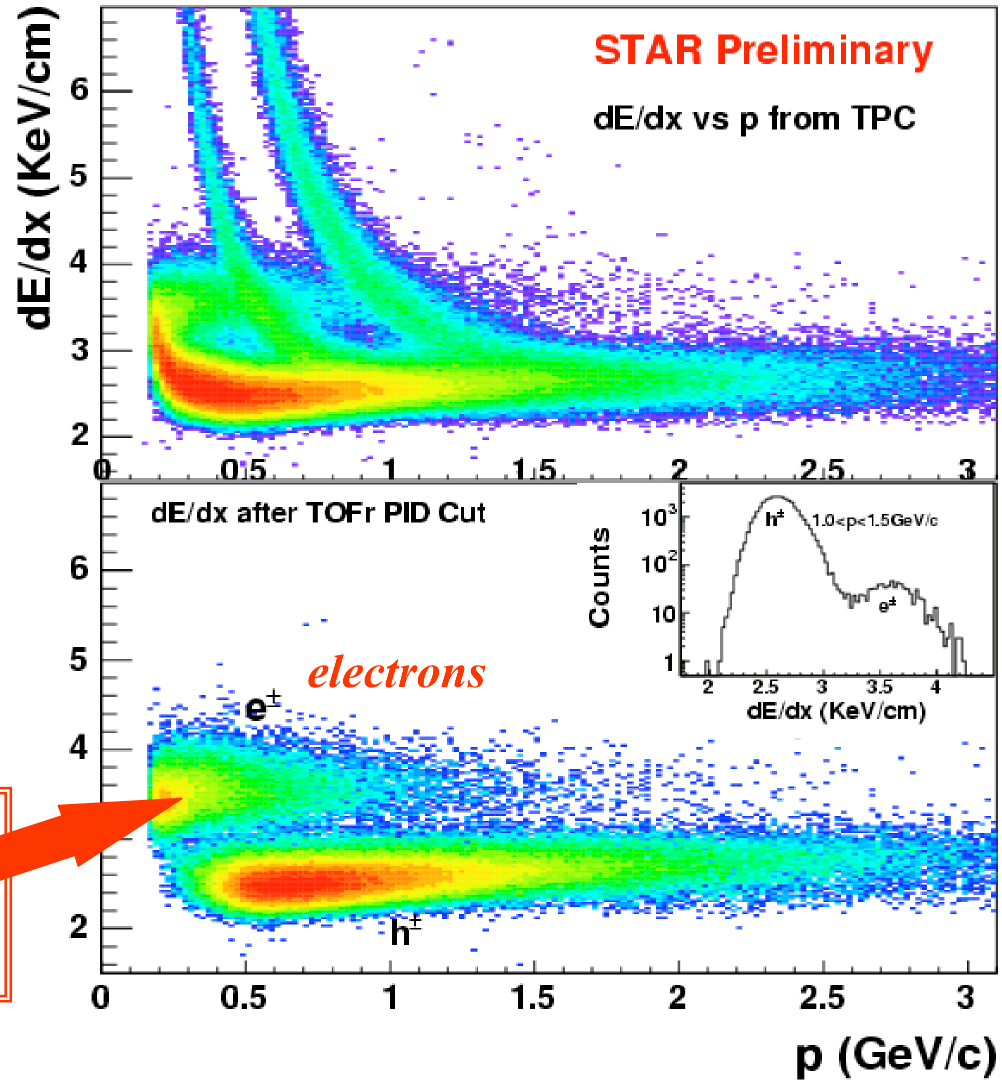
STAR TOFr PID



Hadron identification:
STAR Collaboration, *nucl-ex/0309012*

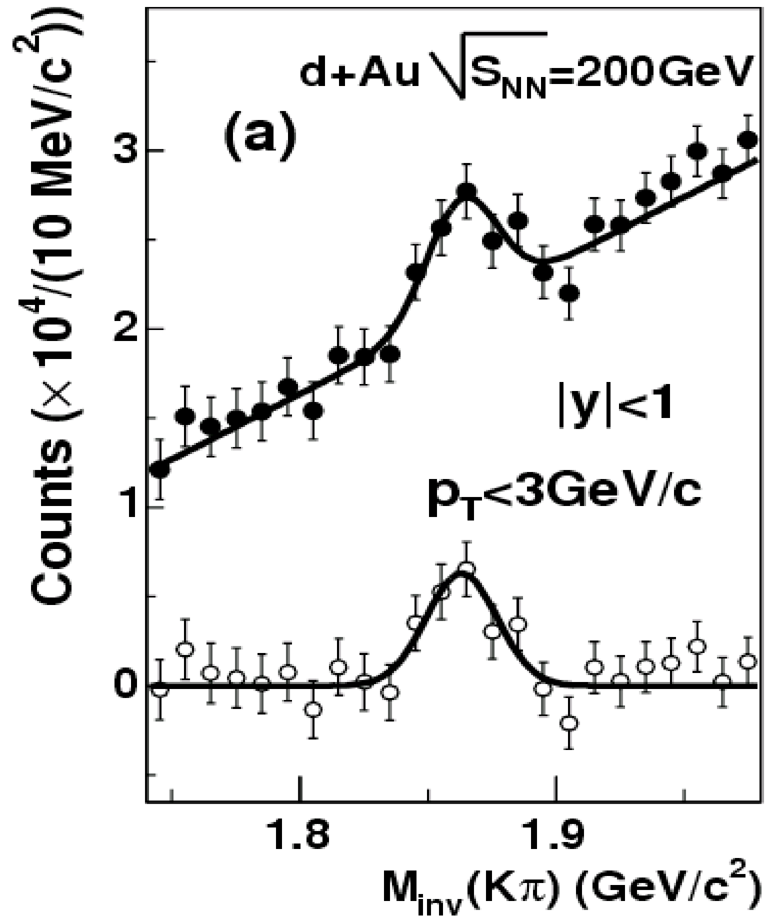
Electron identification:
TOFr |1/ß-1| < 0.03
TPC dE/dx electrons!!!



D^0 direct reconstruction

$$D^0 \rightarrow K^- \pi^+ \text{ (Br. 3.83\%)}$$

STAR Preliminary



C. Adler et al., *Phys. Rev. C 66, 061901(R)(2002)*
H. Zhang, *J. Phys. G 30, S577(2004)*

Electron spectra

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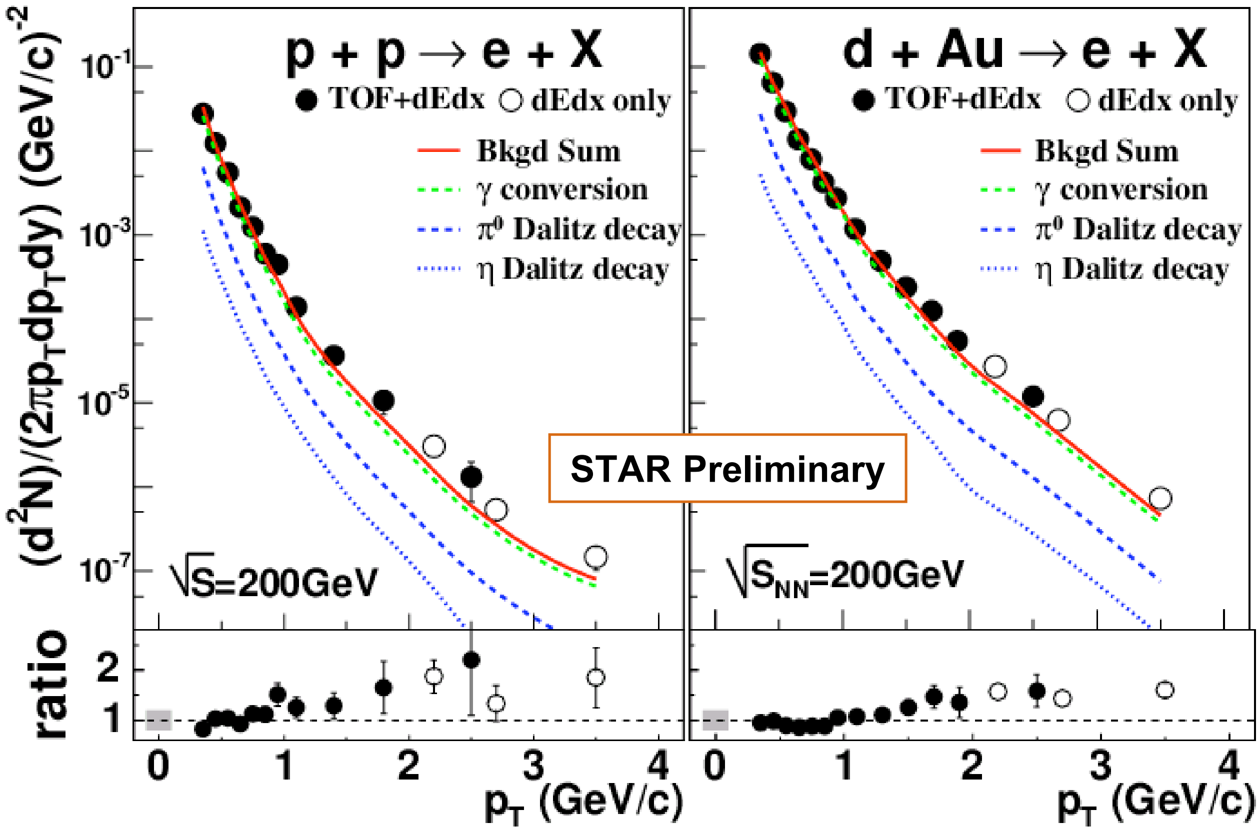
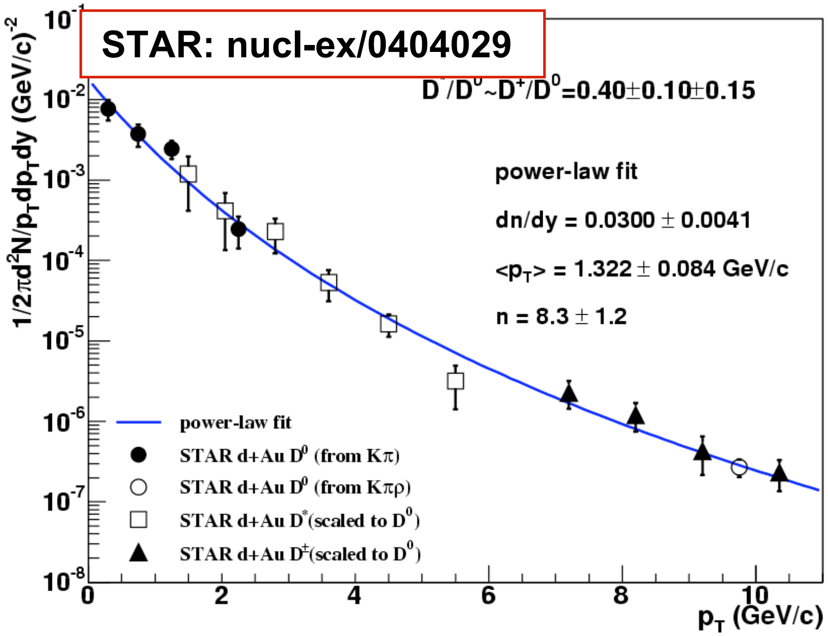


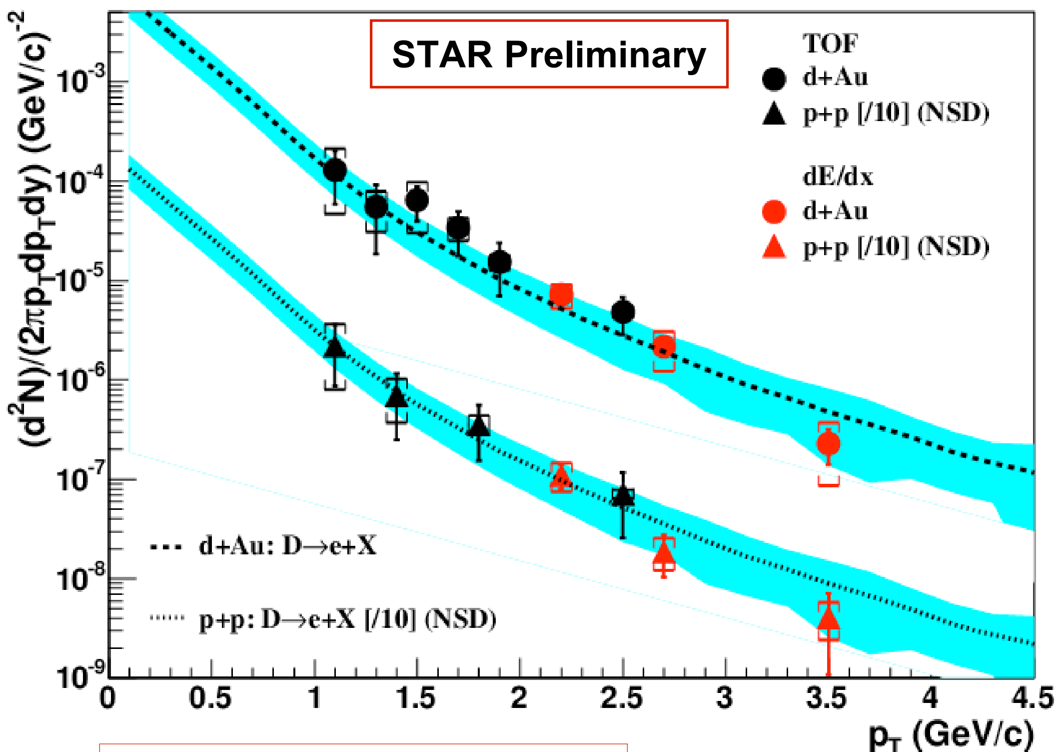
An increasing excess found at higher p_T region, p_T > 1.0 GeV/c,

→Expected contribution of semi-leptonic decays from heavy flavor hadrons

*STAR: **nucl-ex/0407006***

Consistent in D measurements



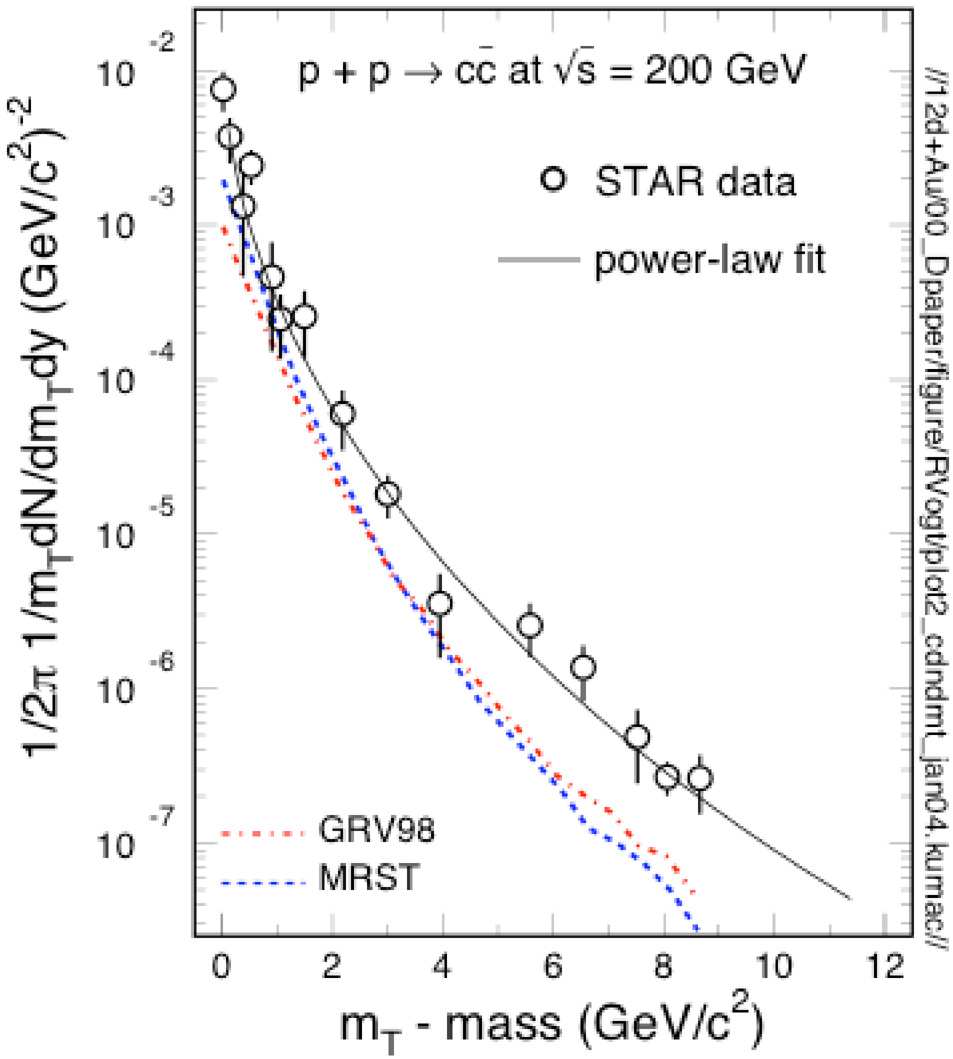


Directly reconstructed D mesons

Electrons from D decay

D and electron spectra are consistent!

Open charm production at RHIC



- pQCD distributions are steeper

-

- Fragmentation with delta function has harder spectrum

-Total cross sections are lower, a factor of 3-5

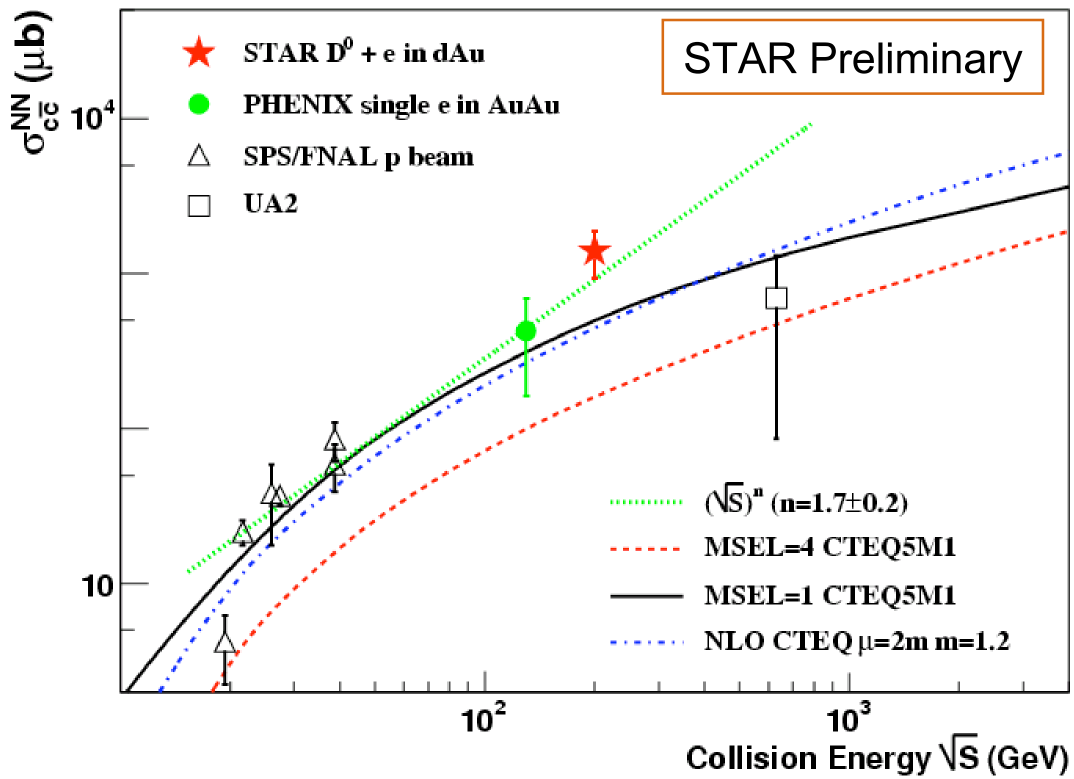
- - *R. Vogt, 2004*

Charm production cross-section

1) NLO pQCD calculations under-predict the ccbar production cross section at RHIC

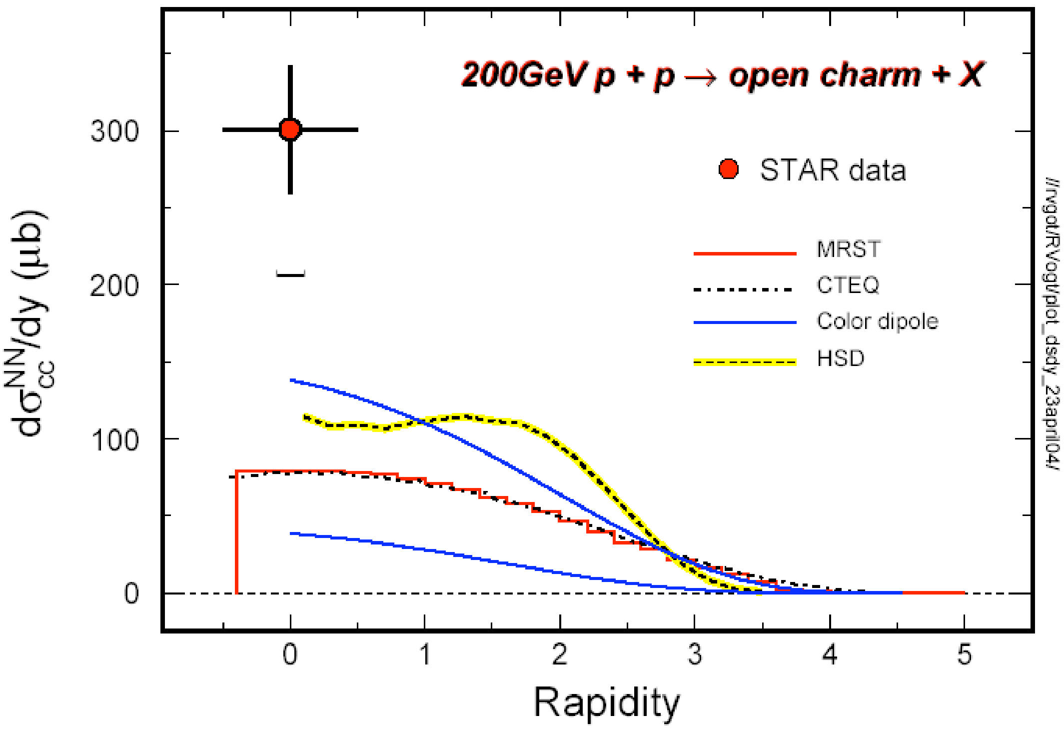
2) Power law for ccbar production cross section from SPS to RHIC:
n ~ 2
(n~0.5 for charged hadrons)

3) Large uncertainties in total cross section due to rapidity width, model dependent(?).



Open charm production at RHIC

J. Raufeisen and J. Peng, Phys.Rev. **D67**, 054008(2003)
HSD: Phys. Rev. **C67** , 054905(2003).



1) d/dy ➪ : a factor from model like Pythia. At 200 GeV, the factor 4.7 was used at STAR.

2) A strong dependent on the method of fragmentation in charm p_T spectra observed, but not on rapidity distributions.

	$dN(D^0)/dy\vert_{y=0}$ (10^{-2})	$d\sigma^{NN}_{c\bar{c}}/dy\vert_{y=0}$ (mb)
D^0	2.8±0.4±0.8	0.29±0.04±0.08
$D^0+e^{\pm}$	2.9±0.4±0.8	0.30±0.04±0.09
D $+e^{\pm}$	2.7±0.3±0.7	0.28±0.03±0.08

Non-photonic electron v_2

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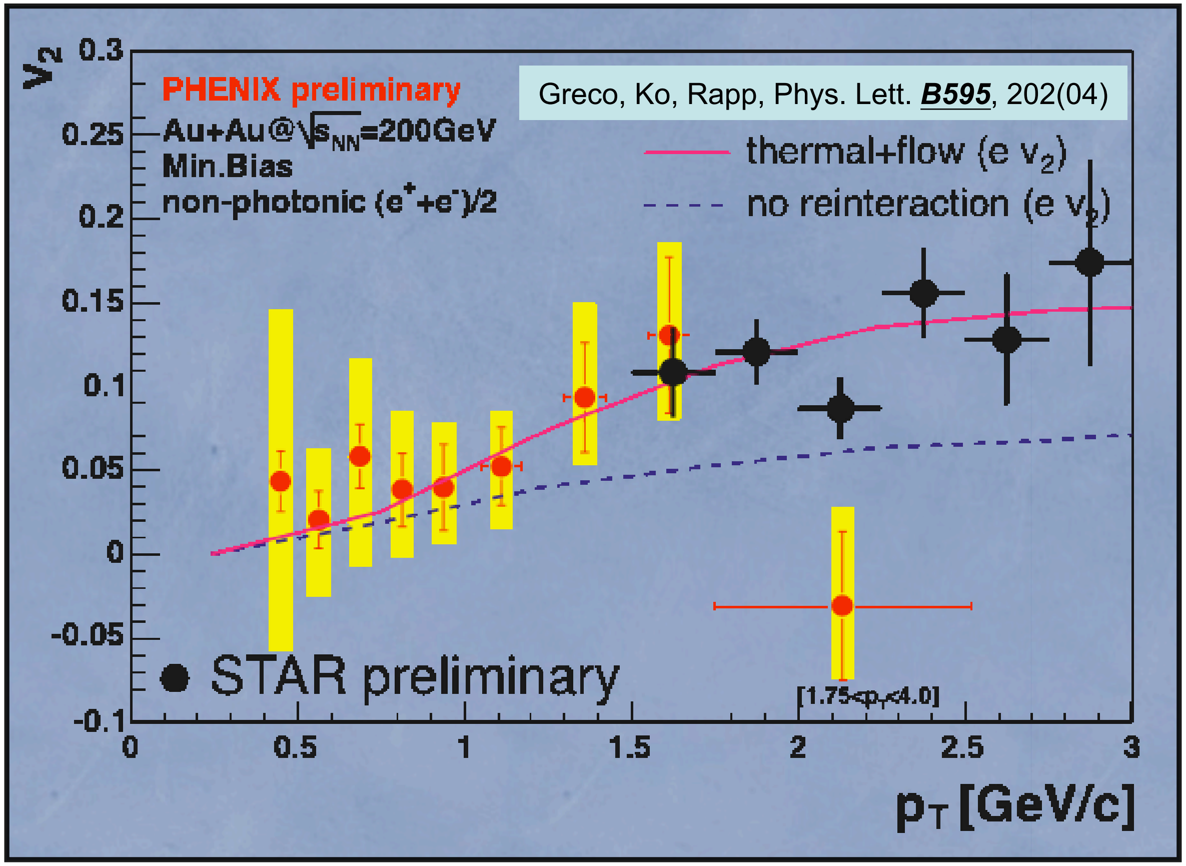
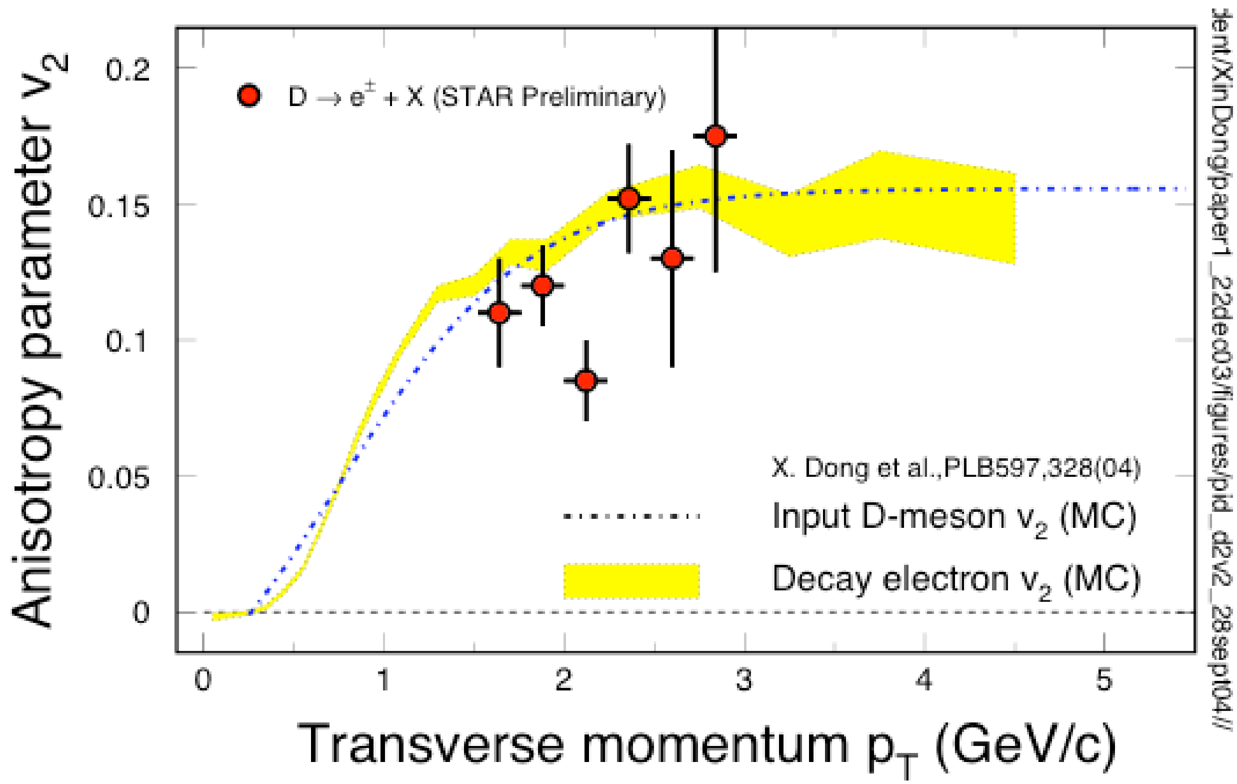


STAR: 0-80% (F.Laue SQM04)
statistical error only
corrected for $e^{\pm}$ from decay

PHENIX: Minimum bias

M. Kaneta *et al*, J.Phys. **G30**, S1217(04)

Open charm v_2 - a comparison



1) *Constituent Quark Scaling for open charm hadron production?*
2) *Flow of charm-quark and the thermalization among light flavors?*
3) *…????*

X. Dong, S. Esumi, P. Sorensen, N. Xu and Z. Xu, Phys. Lett. ***B597****, 328(2004).*

Summary

1) First J/ψ data at RHIC, much more statistics needed.

2) Open charm yields measured in both 200GeV p+p and d+Au collisions. No evidence of deviation from binary collision scaling in d+Au collisions

$$\sigma_{c\bar{c}}^{total} = 700 - 1200 (\mu b)$$

3) Perturbative calculations under predicted both yields and spectrum shape. Hadronization process not under control

4) Study open charm v_2 and J/ψ yields to address thermalization issues at RHIC. The run-IV data will just do that.

Thermal Equilibrium at RHIC

At RHIC, yields of open charm is high:

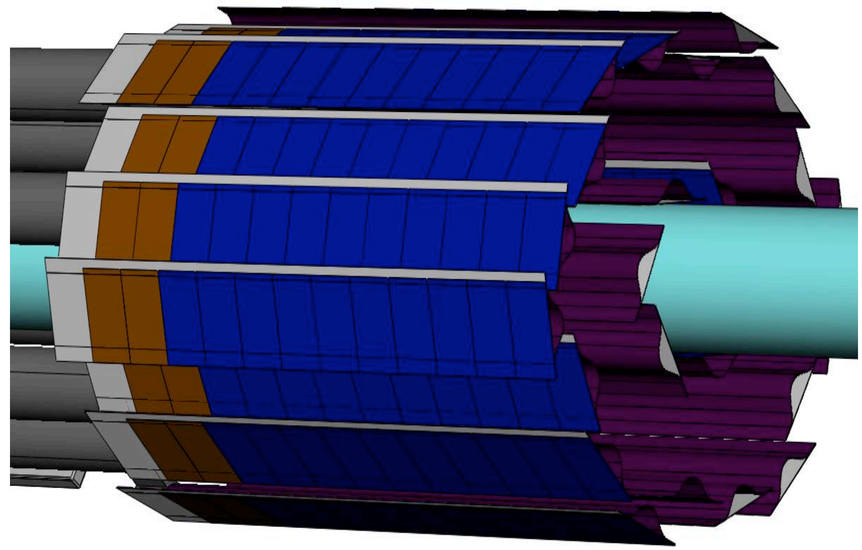
1) The rescattering will lead to **collective motion** and thermalization among partons. Since $m_C >> T_0$ and $m_{u,d,s}$ thermal equilibrium is first reachable among light flavors.

2) Coalescence of charm quarks will lead to the **enhancement of J/ production** and **thermal-like** spectra in central nucleus-nucleus collisions.

➪ **Study open charm and J/ spectra and v_2**
➪ **Study J/ yields versus collision centrality**

Upgrade at STAR

STAR MRPC - TOF



STAR MicroVertex Tracker

Active pixel sensors (APS)
Two layers of thin silicon

- **Full open charm measurements**
- **Full resonance measurements with both hadron and lepton decays**